

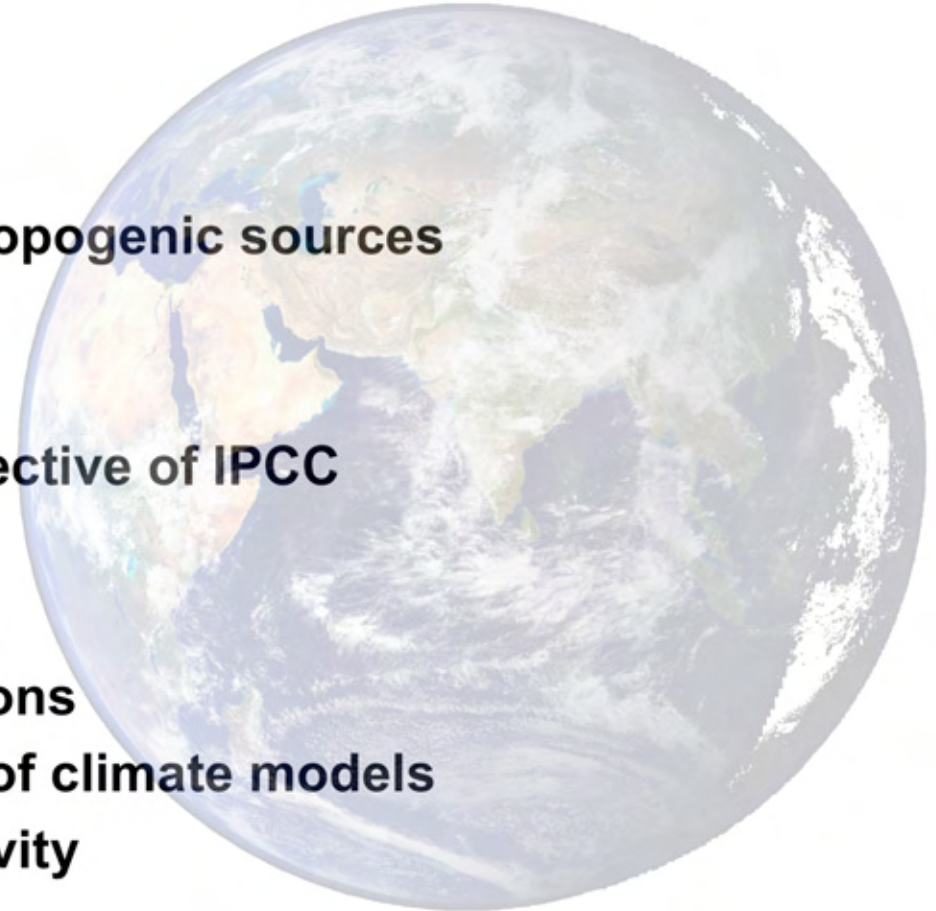
A Climate Model Prediction Perspective

Bill Collins
UC Berkeley and LBL
Berkeley, California

Role of CLARREO: A modeler's view



- **Key issues for climate change:**
 - Detection of climate change
 - Attribution to natural or anthropogenic sources
 - Forecasts of future change
- **State of these issues from perspective of IPCC**
- **Central questions for models:**
 - Veracity of near-term predictions
 - Evaluation and improvement of climate models
 - Distribution of climate sensitivity

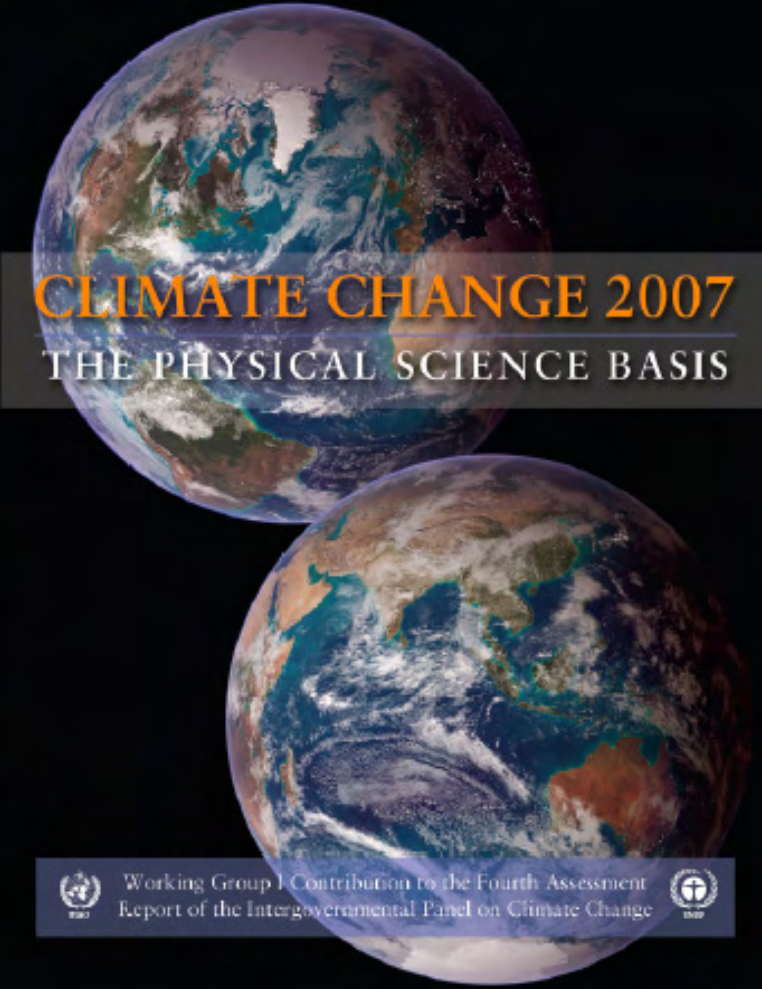


Key findings from IPCC WG1



CLIMATE CHANGE 2007
THE PHYSICAL SCIENCE BASIS

Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change



CLIMATE CHANGE 2007
THE PHYSICAL SCIENCE BASIS

CLIMATE CHANGE 2007 - The Physical Science Basis
Contributions of Working Group I to the Fourth Assessment Report of the IPCC
(ISBN 978 0 521 88009 1 Hardback, 978 0 521 70596 7 Paperback)

CLIMATE CHANGE 2007 - Impacts, Adaptation and Vulnerability
Contributions of Working Group II to the Fourth Assessment Report of the IPCC
(ISBN 978 0 521 88010 7 Hardback, 978 0 521 70597 4 Paperback)

CLIMATE CHANGE 2007 - Mitigation of Climate Change
Contributions of Working Group III to the Fourth Assessment Report of the IPCC
(ISBN 978 0 521 88011 4 Hardback, 978 0 521 70598 1 Paperback)

Climate Change 2007 - The Physical Science Basis is the most comprehensive and up-to-date scientific assessment of past, present and future climate change. The report provides:

- the most complete and quantitative assessment of how human activities are affecting the radiative energy balance in the atmosphere
- a more extensive assessment of changes observed throughout the climate system than ever before using the latest measurements covering the atmosphere, land surface, oceans, and snow, ice and frozen ground
- a detailed assessment of past climate change and its causes
- the first probabilistic assessment of climate model simulations and projections using detailed atmosphere-ocean coupled models from 18 modelling centres around the world
- a detailed assessment of climate change observations, modelling, and attribution for every continent

Simply put, this latest assessment of the IPCC will again form the standard scientific reference for all those concerned with climate change and its consequences, including students and researchers in environmental science, meteorology, climatology, biology, ecology and atmospheric chemistry, and policy makers in governments and industry worldwide.

From reviews of the Third Assessment Report - Climate Change 2001:

'The detail is truly amazing... invaluable works of reference... no reference or science library should be without a set of the IPCC volumes... warmly and enthusiastically recommended to all readers.'
Journal of Meteorology

'This well-edited set of three volumes will surely be the standard reference for nearly all arguments related with global warming and climate change in the next years. It should serve the cause in the liberation of atmospheric and climate research institutes and those administrative and political institutions which have to deal with global change and sustainable development.'
Meteorologische Zeitschrift

'... likely to remain a vital reference work until further research confirms the details outlined by the time of the next survey... another significant step forward in the understanding of the likely impacts of climate change on a global scale.'
International Journal of Climatology

'The IPCC has conducted what is arguably the largest, most comprehensive and transparent study ever undertaken by mankind... The result is a work of substance and authority, which only the foolish would dismiss.'
Wind Engineering

'The subject is explored in great depth and should prove valuable to policy makers, researchers, analysts, and students.'
American Meteorological Society

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Evidence for physical climate change



Grinnell Glacier, Montana, 1938



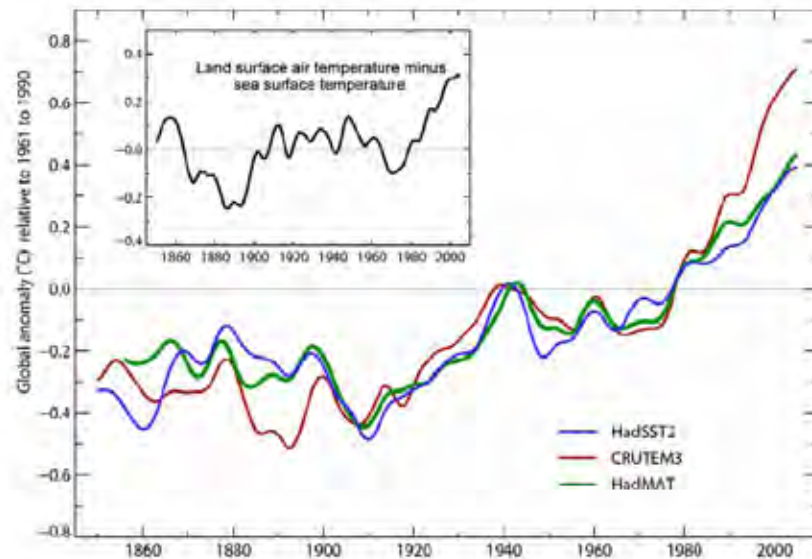
Grinnell Glacier, Montana, 2005



Increasing global temperatures

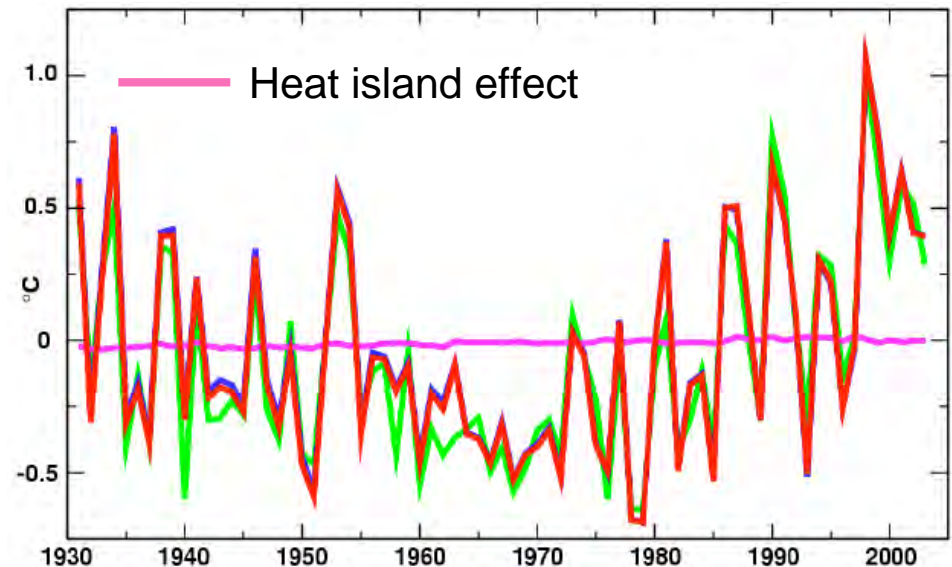


Global Temperatures



IPCC AR4, 2007

Urban Heat Island Effect

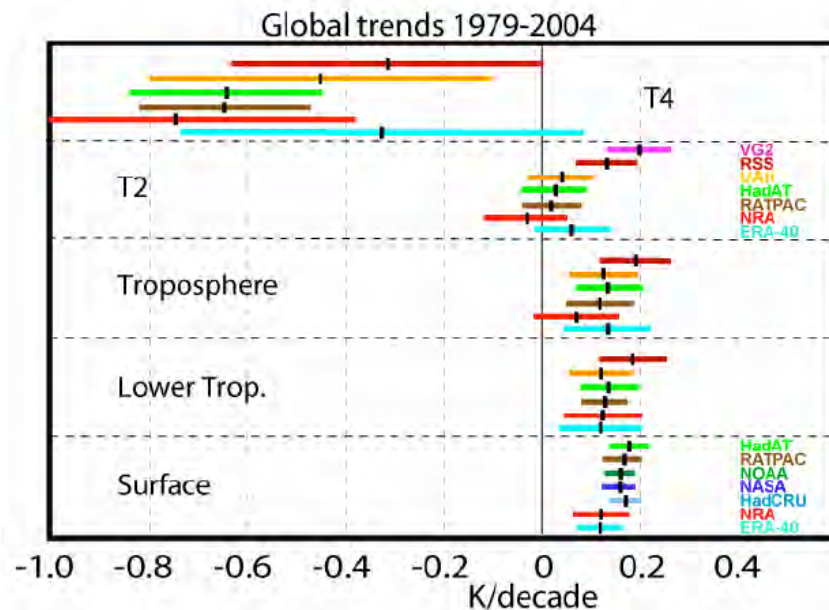


- Earth has warmed by $0.76 \pm 0.19\text{K}$ since 1850.
- Measurement artifacts do not affect global trends.

Atmospheric temperature and moisture

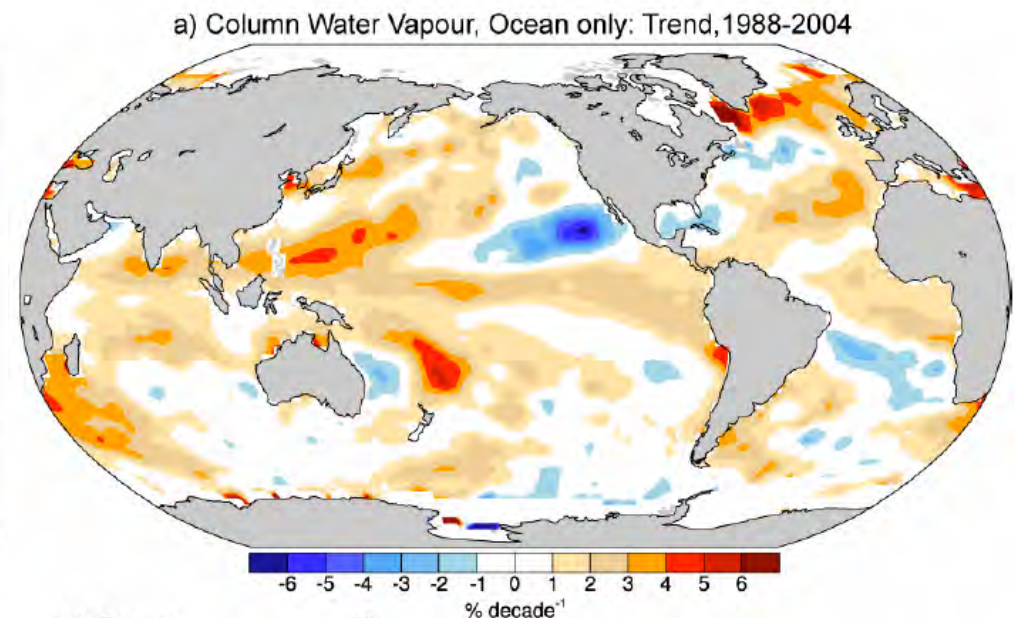


Air Temperature Trends



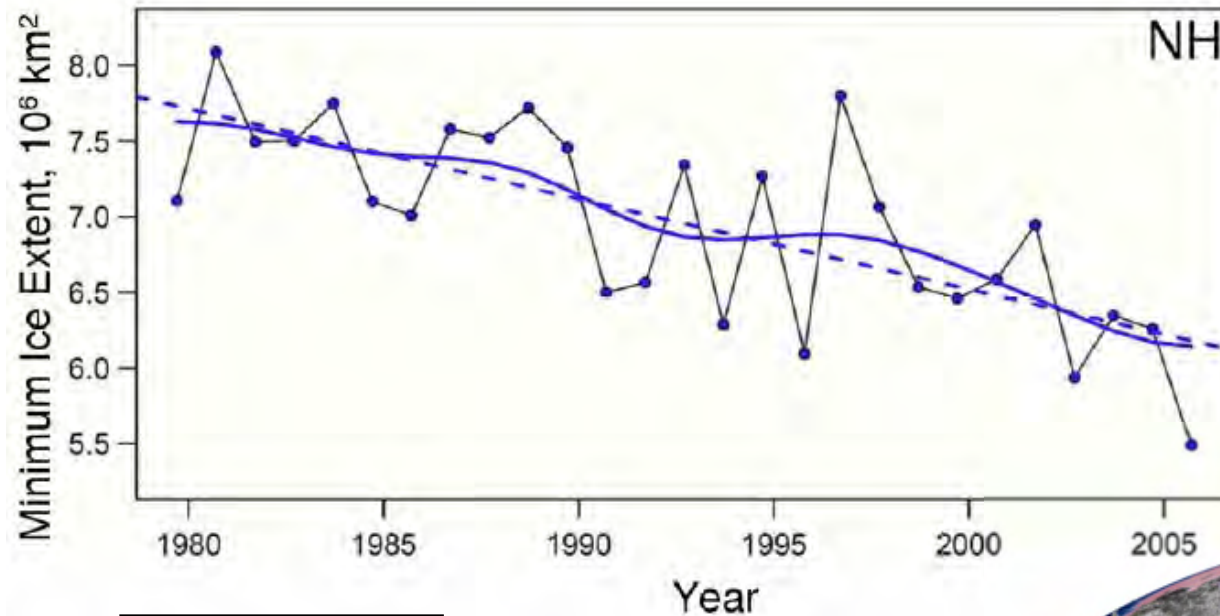
IPCC AR4, 2007

Atmospheric Moisture Trends



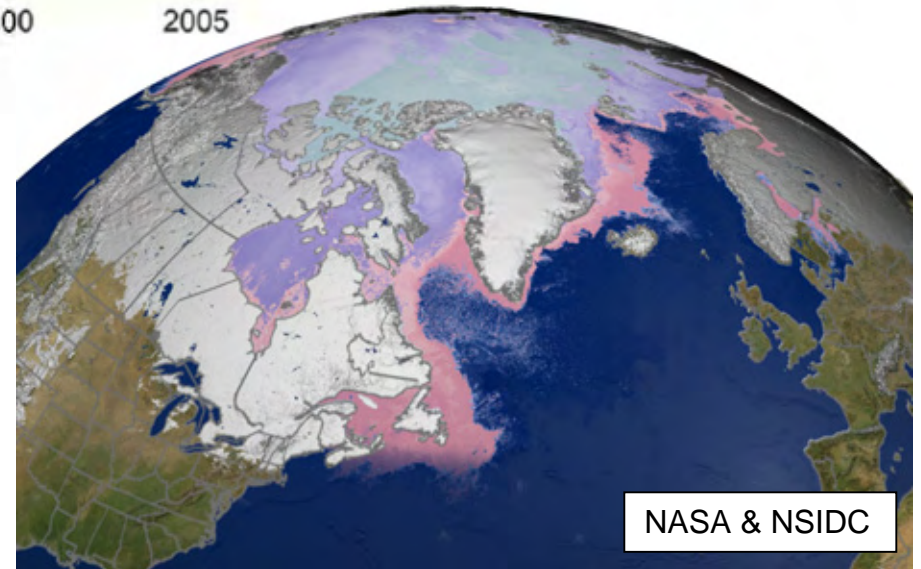
- Troposphere is warming by 0.16K to 0.18K per decade.
- Tropospheric humidity is increasing by 1.2%/decade.

Reductions in Arctic sea ice



IPCC AR4, 2007

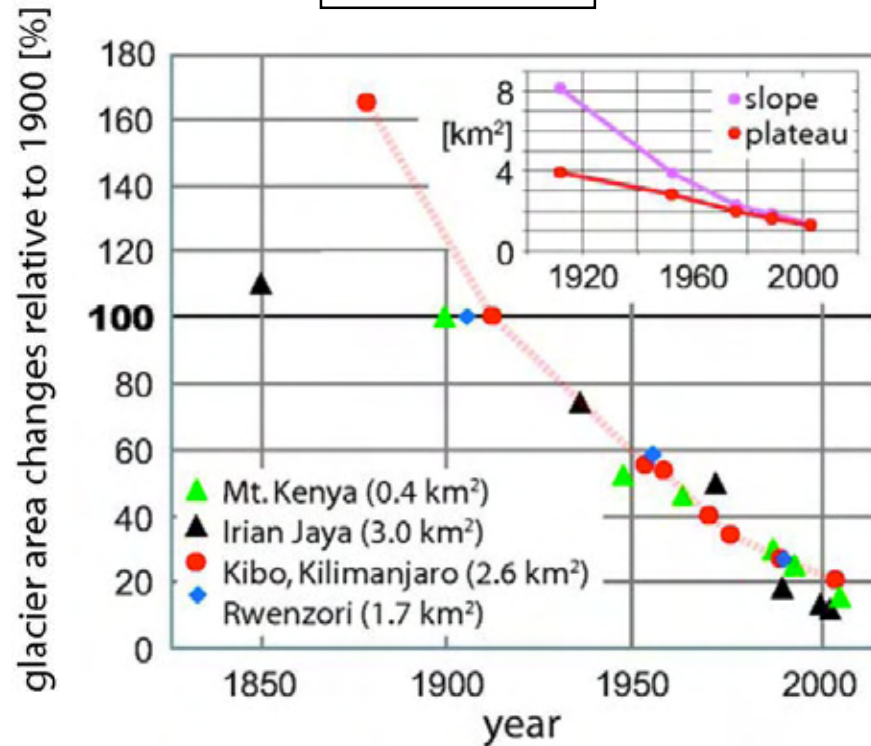
- Arctic summer sea ice extent is shrinking at $7.4 \pm 2.4\%$ per decade.



NASA & NSIDC

Trends in land glaciers and ice

Glacial Area



Gangotri Glacier, Northern India

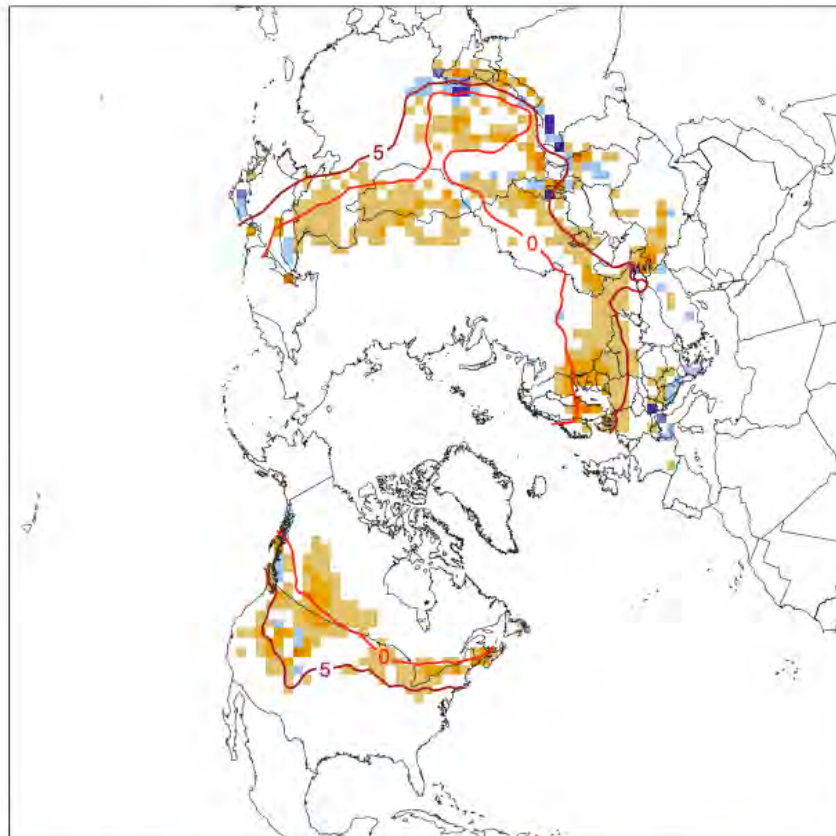


- Mass loss from glaciers since 1991 is 0.77 ± 0.22 mm/year SLE.
- This accounts for approximately 1/4 of the observed sea-level rise.

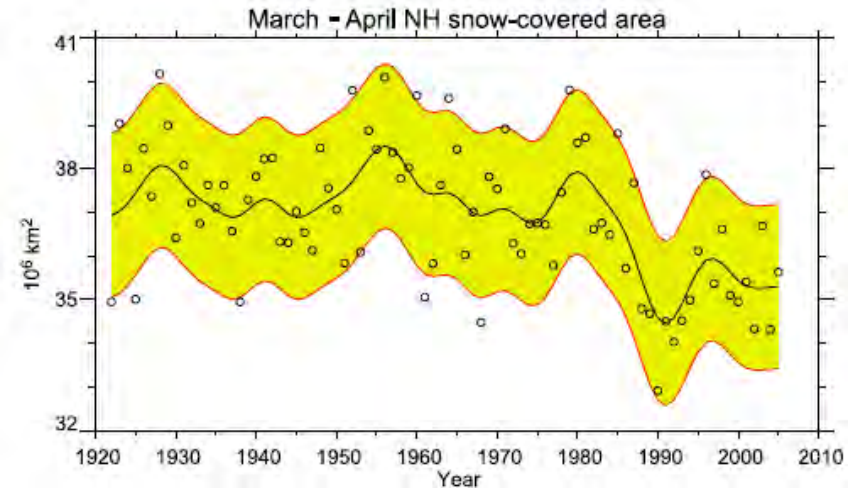
Trends in N. hemisphere snow cover



March — April Snow Departure
(1988 - 2004) minus (1967 - 1987)

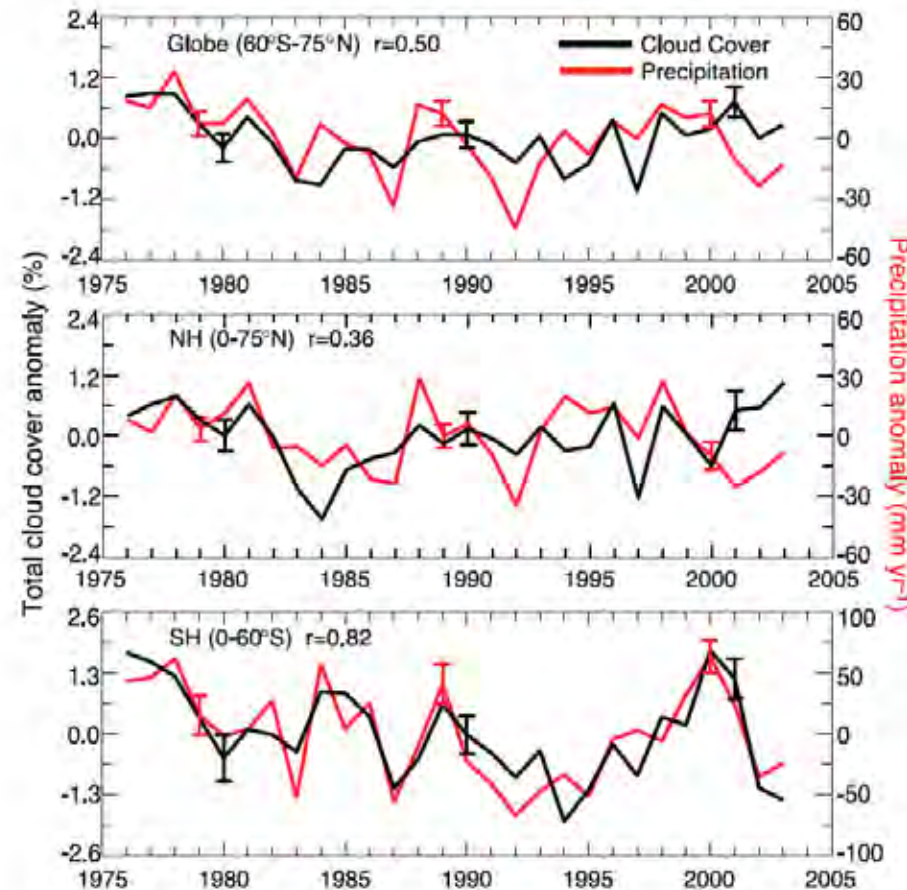


-36 to -26 -25 to -16 -15 to -6 -5 to 5 6 to 15 16 to 25 26 to 38



- Since 1988, snow cover has declined by 5%.
- Linear trend is $-0.9 \pm 0.4\%$ per decade.

Trends in global and regional cloud



- Evidence generally supports reduction in high cloud amounts from 1980s to 1990s.
- There are substantial uncertainties in magnitude (and sign) in decadal trends.

CLARREO and climate-change detection

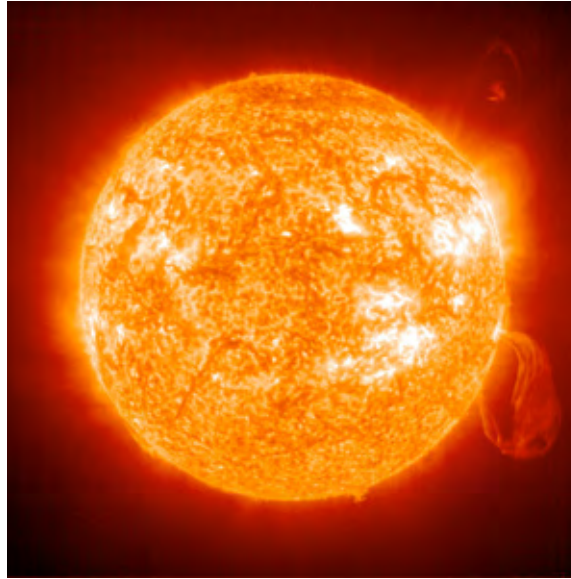


- **Accurate decadal-length records are essential for detection.**
- **Temperature and humidity will continue to be key fields.**
- **Detection of long-term changes in temperature gradients is important for atmospheric dynamics and regional climate.**
- **Reduction in land and sea-ice, frozen soil, and snow are manifest -- impacts on planetary albedo and feedbacks?**
- **Trends in low and mid-level cloudiness are very uncertain.**
- **Is the recent reduction in high-level cloudiness supported by other data, and does it represent a long-term trend?**

Attribution of recent climate changes



Volcanic eruptions



Solar variability



Human Pollution

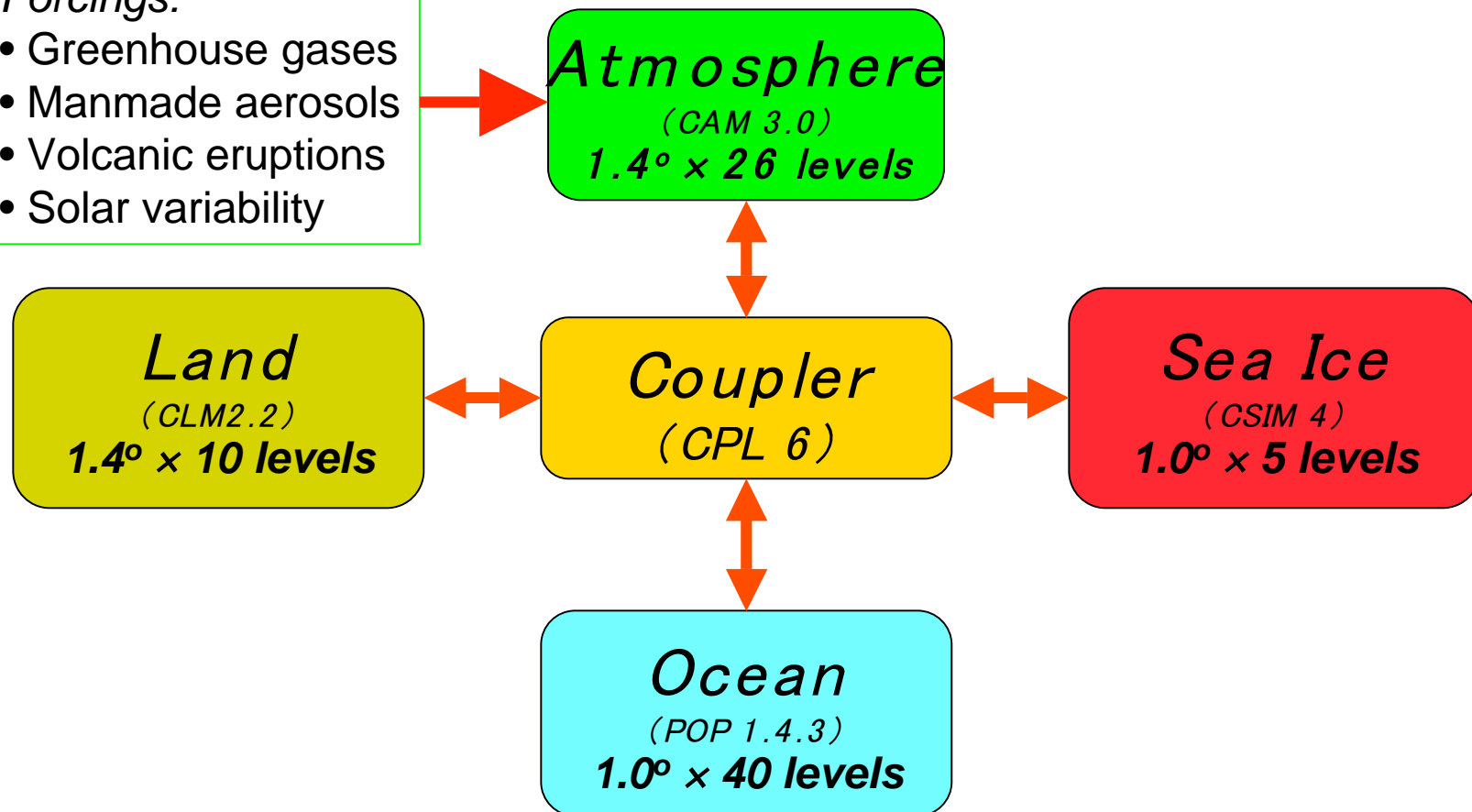
- Attribution has and will continue to be based primarily on:
 - Temperature
 - Ocean heat content
- Atmospheric moisture can now be used for attribution as well.

Method for attribution: Climate models



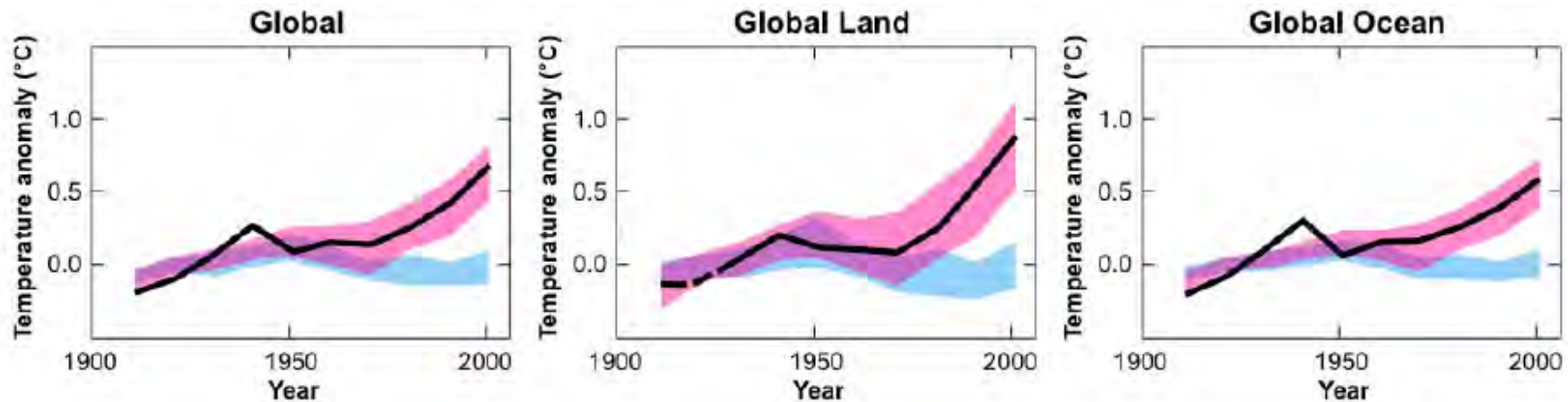
Forcings:

- Greenhouse gases
- Manmade aerosols
- Volcanic eruptions
- Solar variability



CCSM3 Model: <http://www.ccsm.ucar.edu>

Attribution of past climate change



— Observations
All Forcings
Natural Forcings

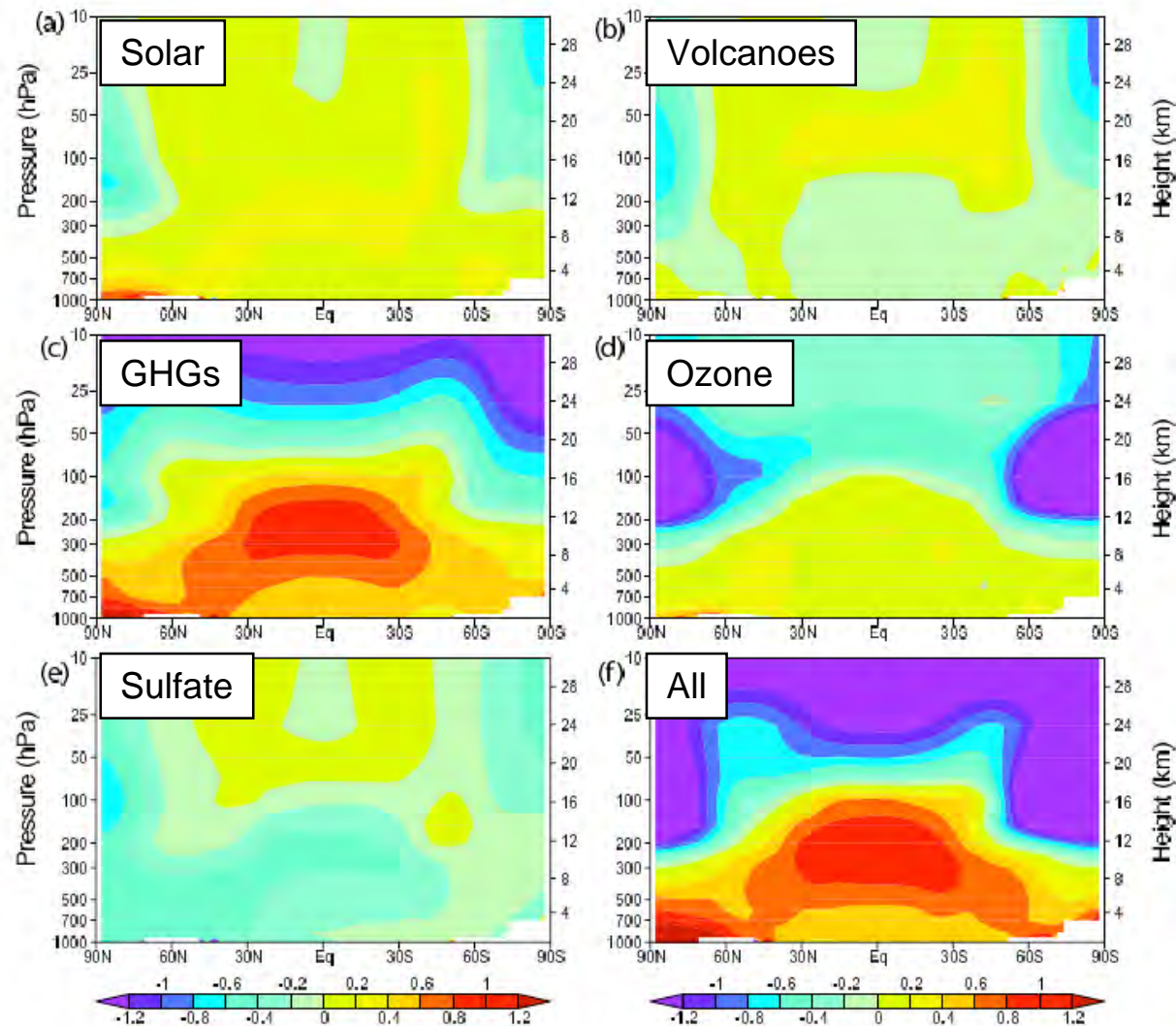
- Models with only natural forcings do not match observations.
- It is very likely (>90%) humans are cause of recent warming.

IPCC AR4, 2007

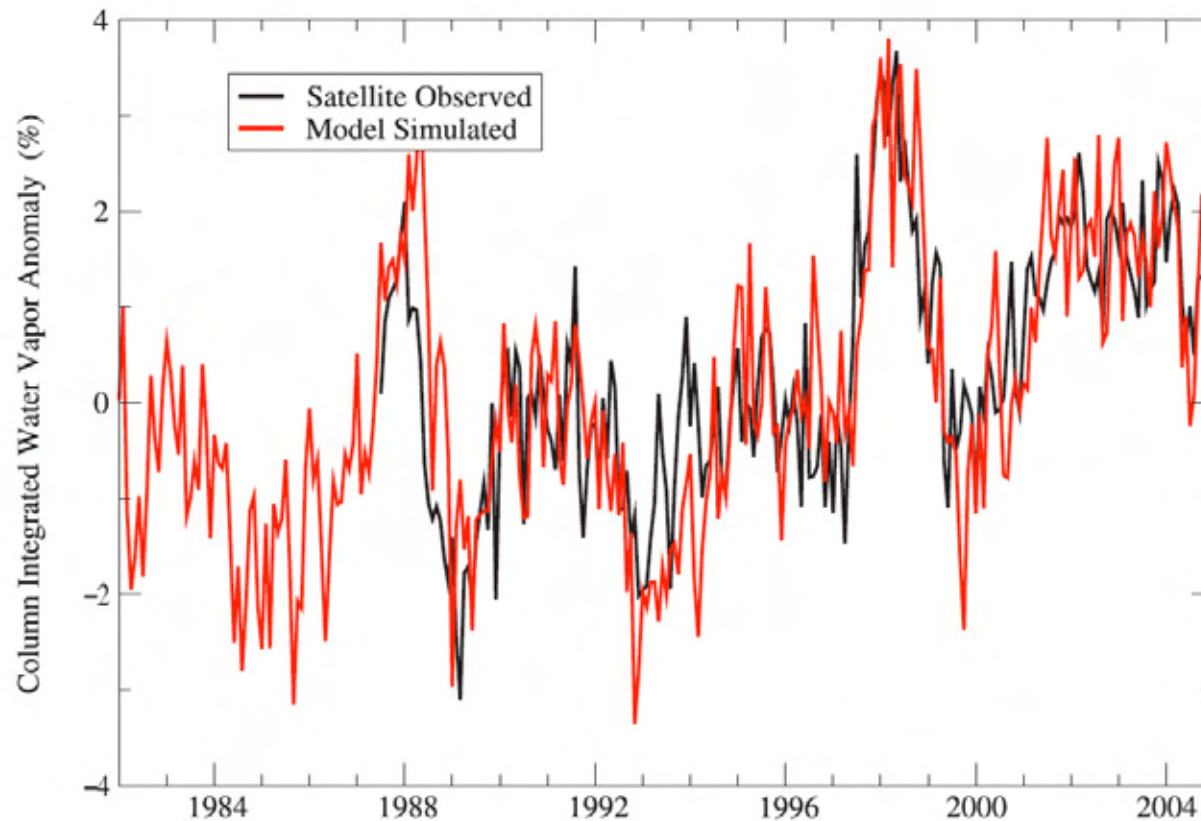
Attribution with optimal fingerprinting



Zonal mean atmospheric temperature change from 1890 to 1999 ($^{\circ}\text{C}/\text{Century}$)

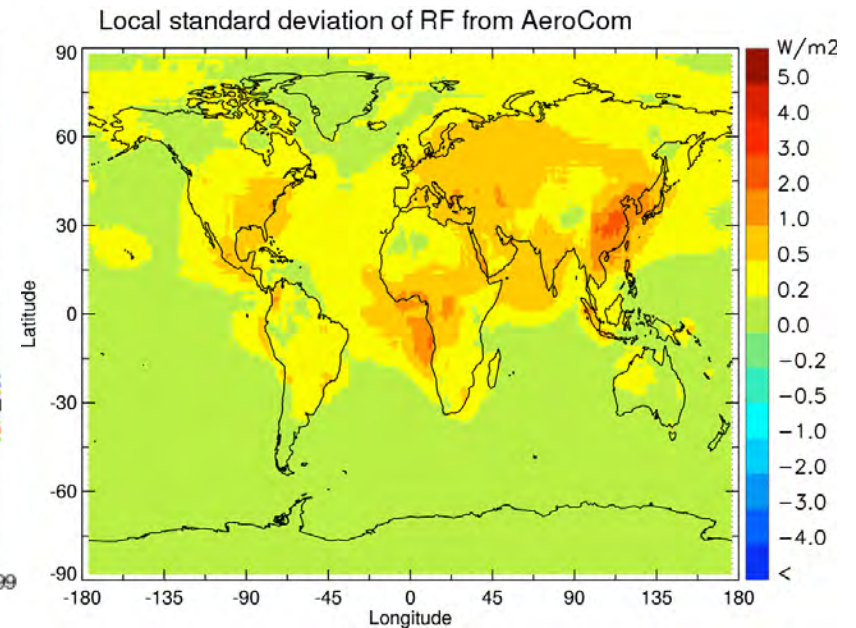
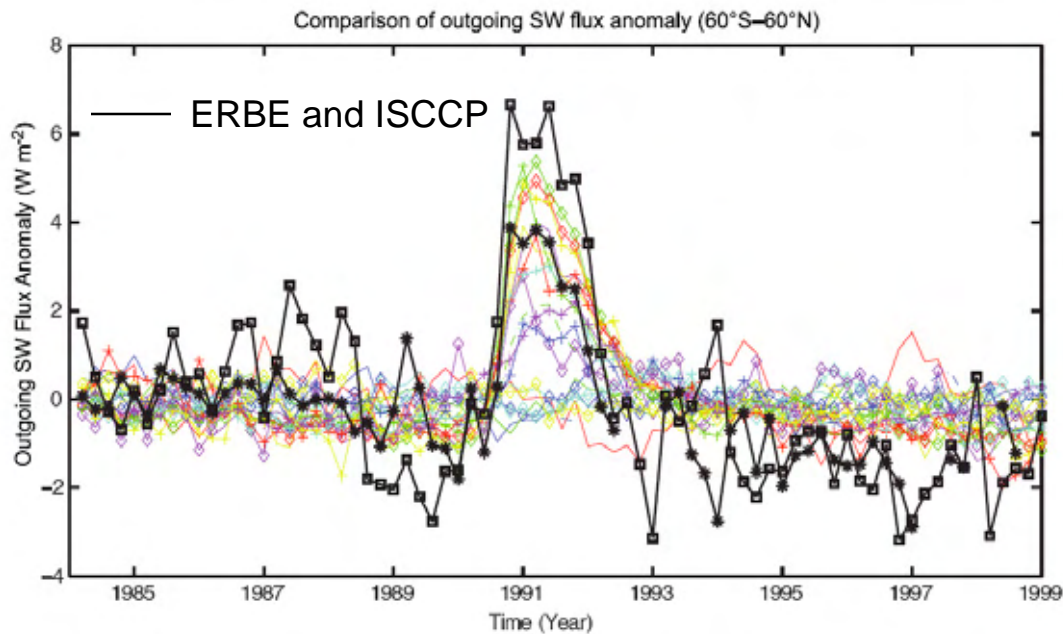


Changes in atmospheric humidity



- Models forced with observed SSTs reproduce 1.2%/decade trend.
- Fingerprinting shows human forcing is primary cause (Santer, 2007).

Principal uncertainties in attribution

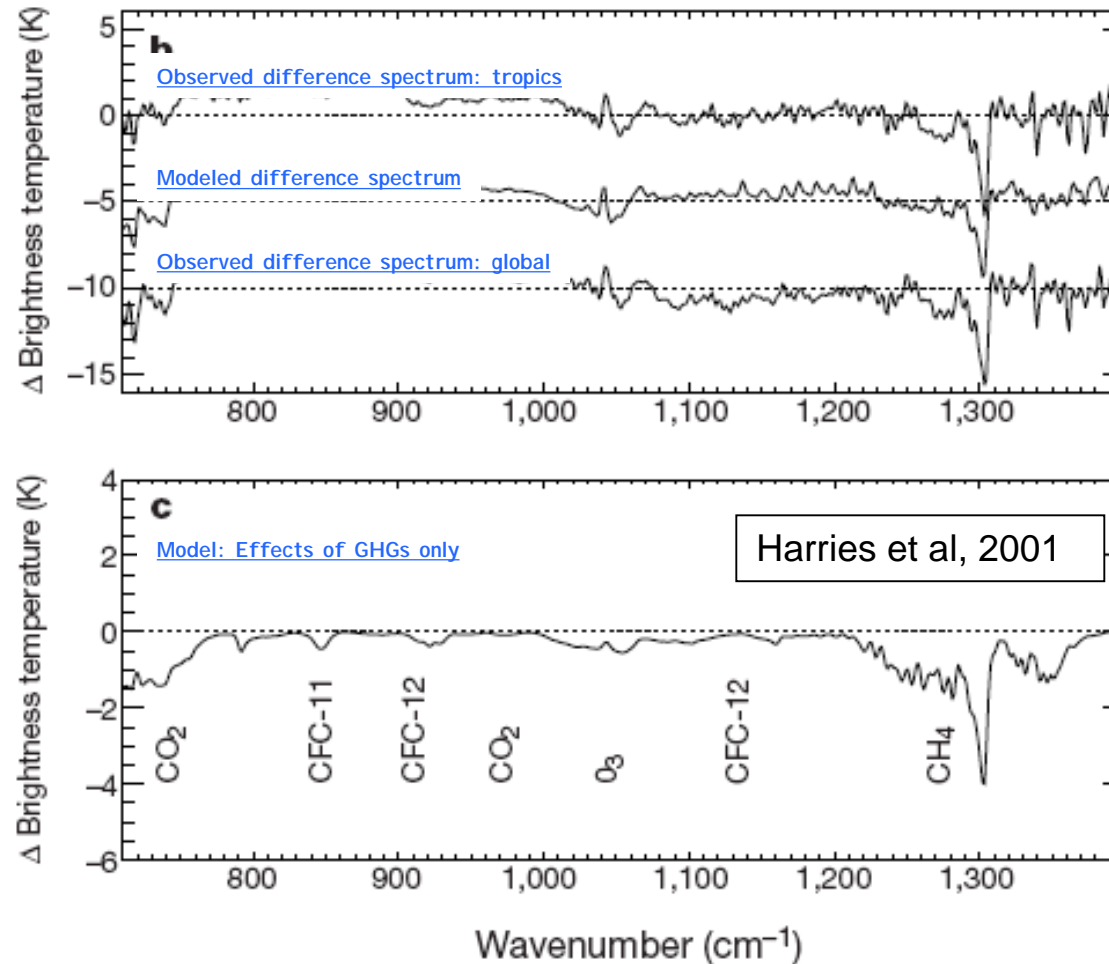


- Aerosol forcing remains quite uncertain, both in models and data.
- Forcing for 20th C. from inverse methods ranges from -1.7 to -0.1 Wm⁻².

Effects of GHG Increases over 1970-1997: *Direct evidence of anthropogenic forcing*



Differences between TES and IRIS in mid-infrared Wavelengths



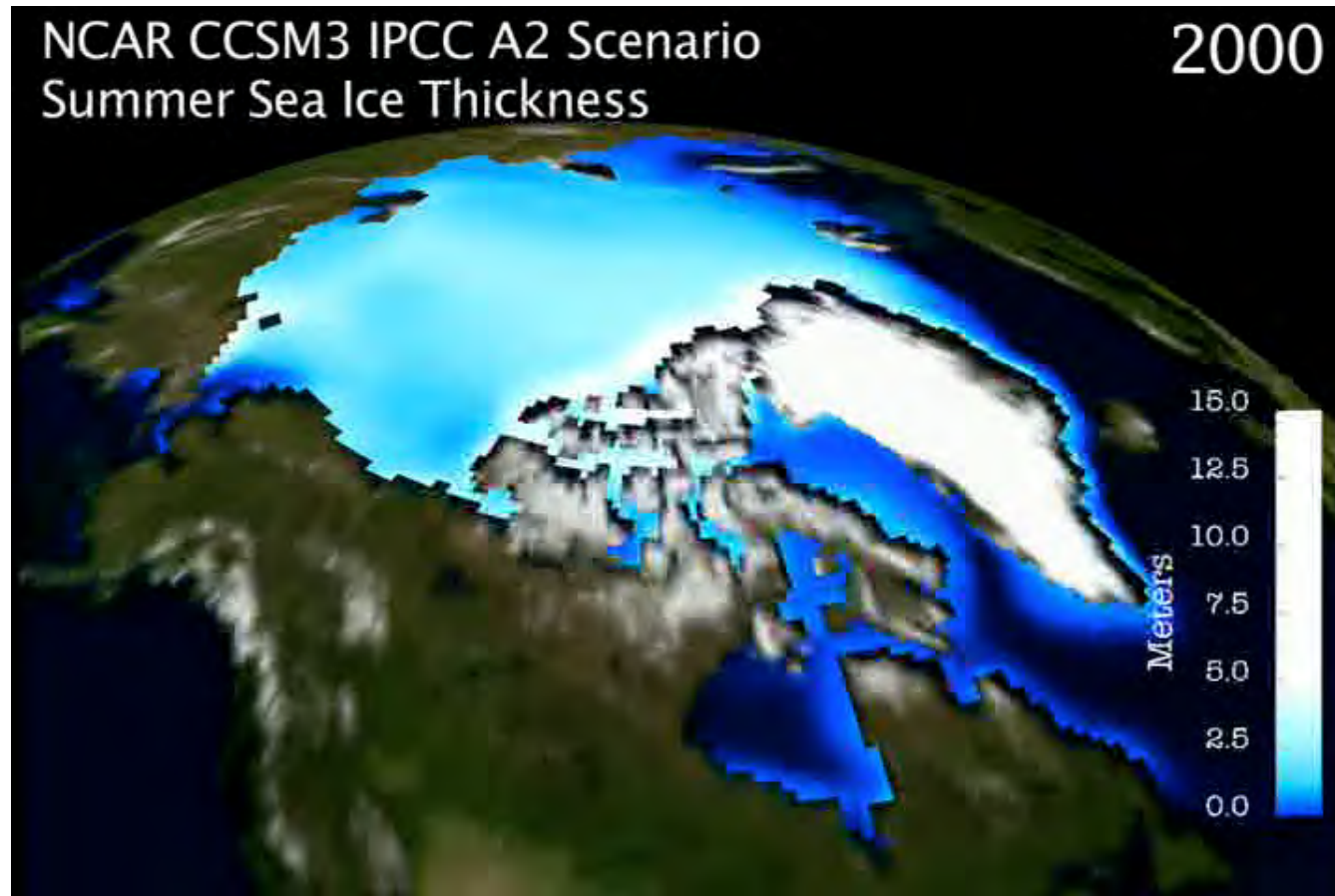
Harries et al, 2001

CLARREO and climate-change attribution

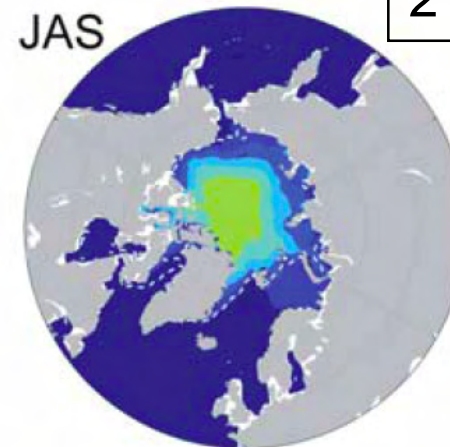
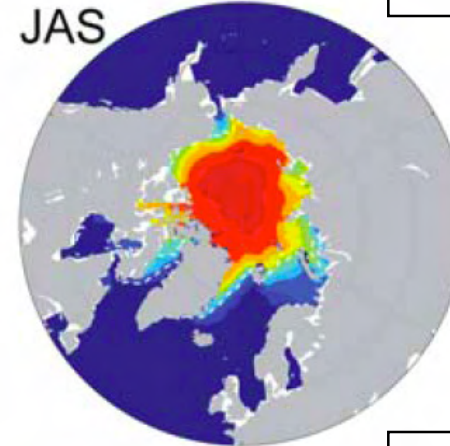
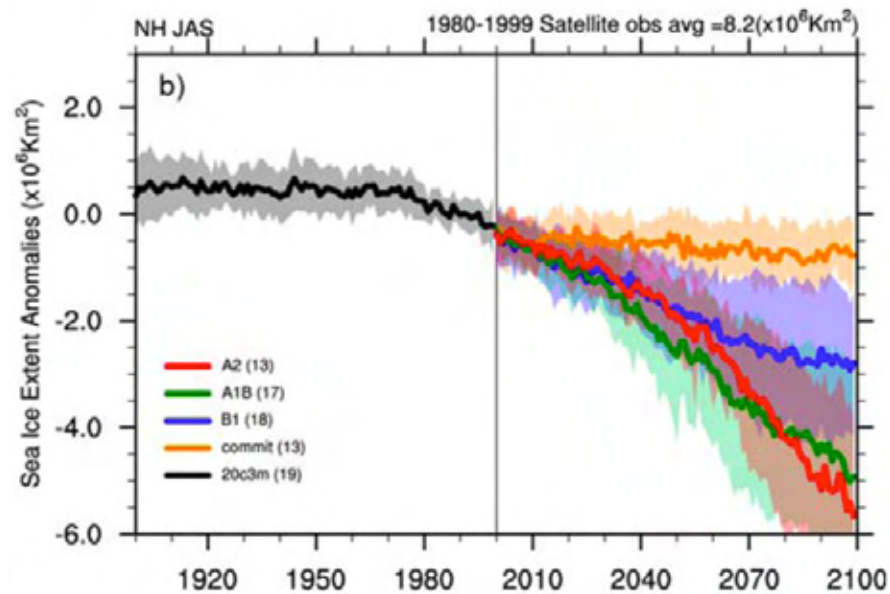


- Accurate decadal-length records are essential for attribution.
- Temperature and humidity will continue to be key fields.
- Detection of long-term changes in temperature gradients is vital for fingerprinting studies.
- Models exhibit large variations in albedo and albedo trends.
- Long-term measurements of albedo require cross-calibration.
- It is critical to monitor the Earth's infrared spectrum for:
 - Effects of long and short-lived greenhouse gases
 - Evidence for natural forcing trends, in particular dust

Future evolution of the Earth's climate



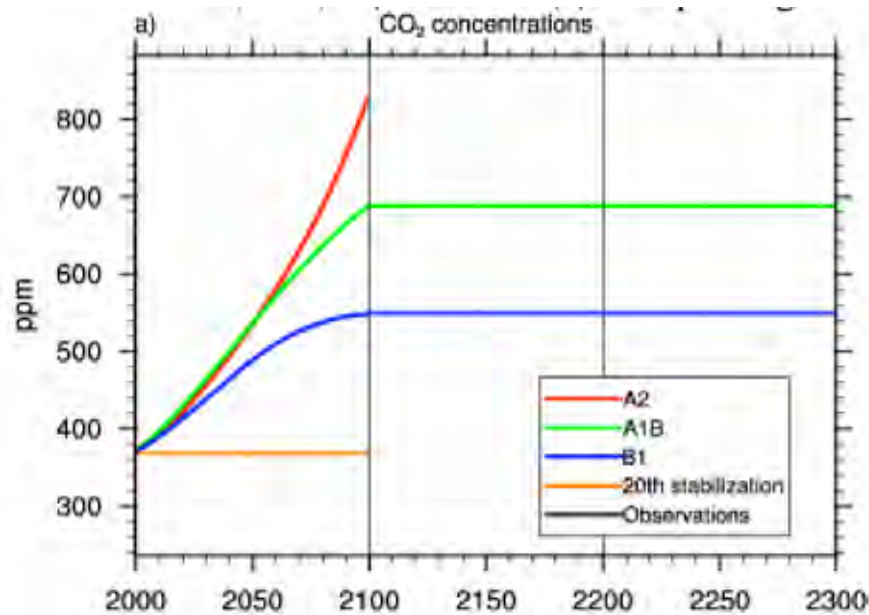
Further reductions in Arctic sea ice



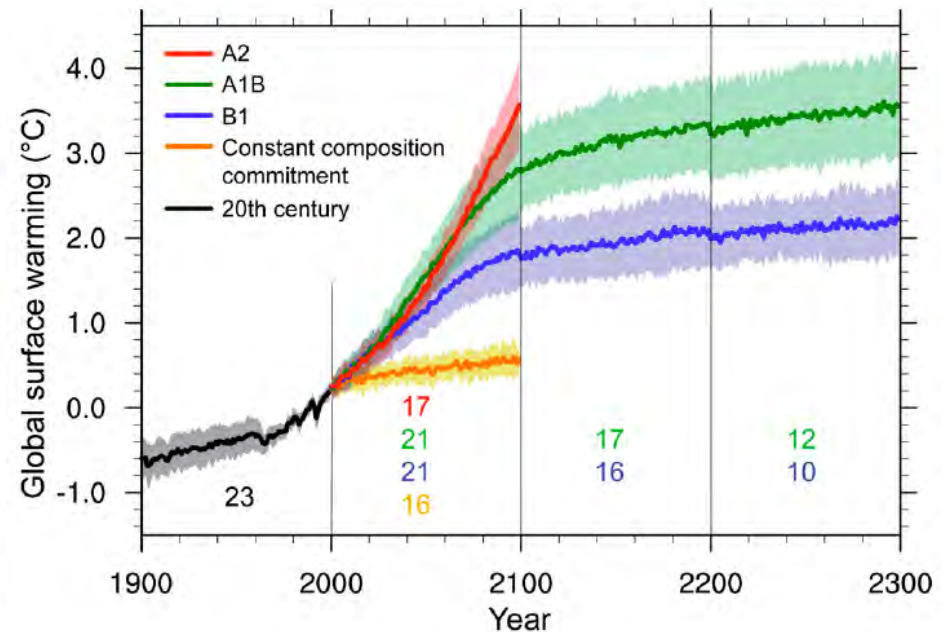
Projections for global temperatures



Emissions Scenarios

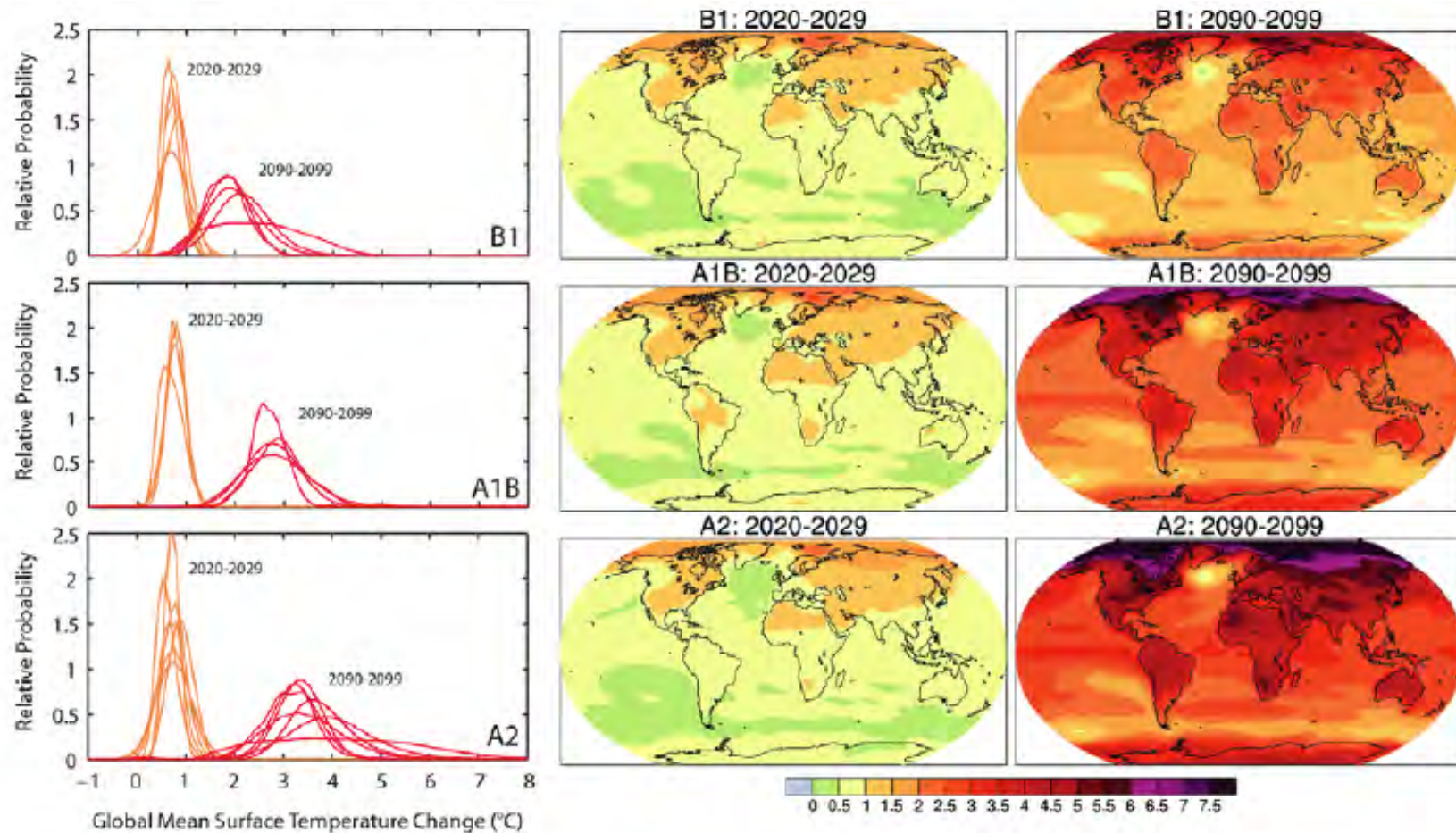


Global Temperature Projections



- Global temperatures could increase by 1.7 to 3.2K.

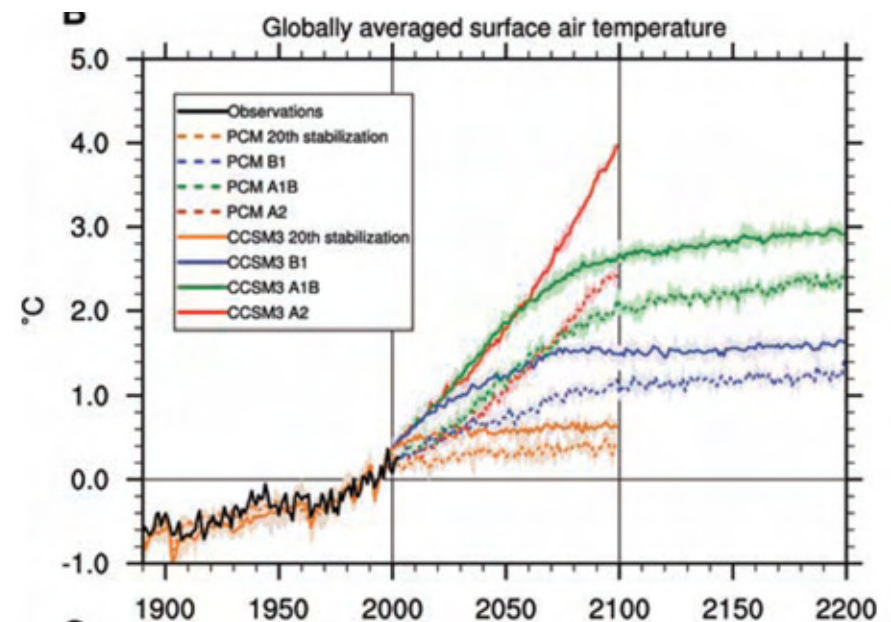
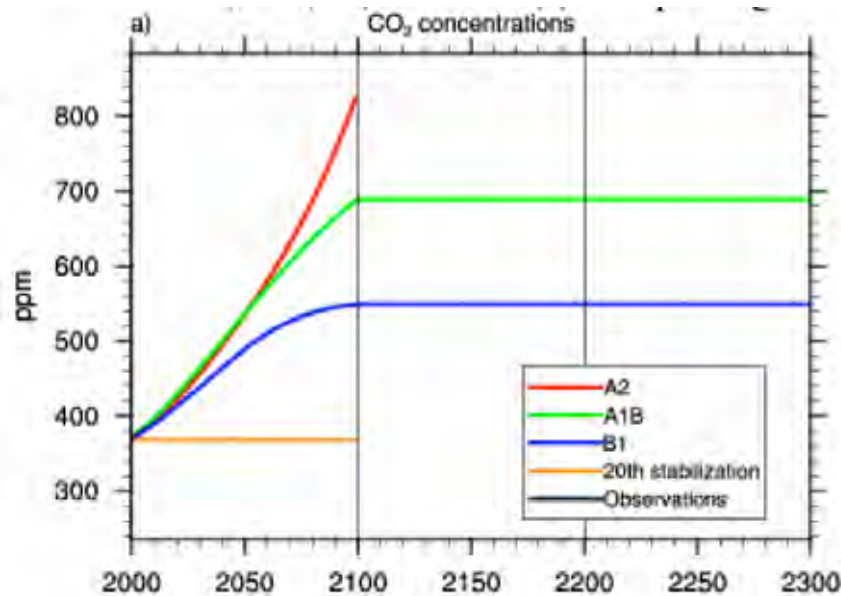
Projection of regional temperatures



IPCC AR4, 2007

- Roughly 2/3 of warming by 2030 is from historical changes.
- Warming by 2030 exceeds 20th C natural variability by >2x.

Decadal projections of temperature



Meehl et al, 2005

- Between 50 to 70% of warming in 2050 relative to pre-industrial periods is “committed”.
- Therefore the short-range predictions are relatively insensitive to socioeconomic scenarios.

Transient Climate Response and Equilibrated Climate Sensitivity

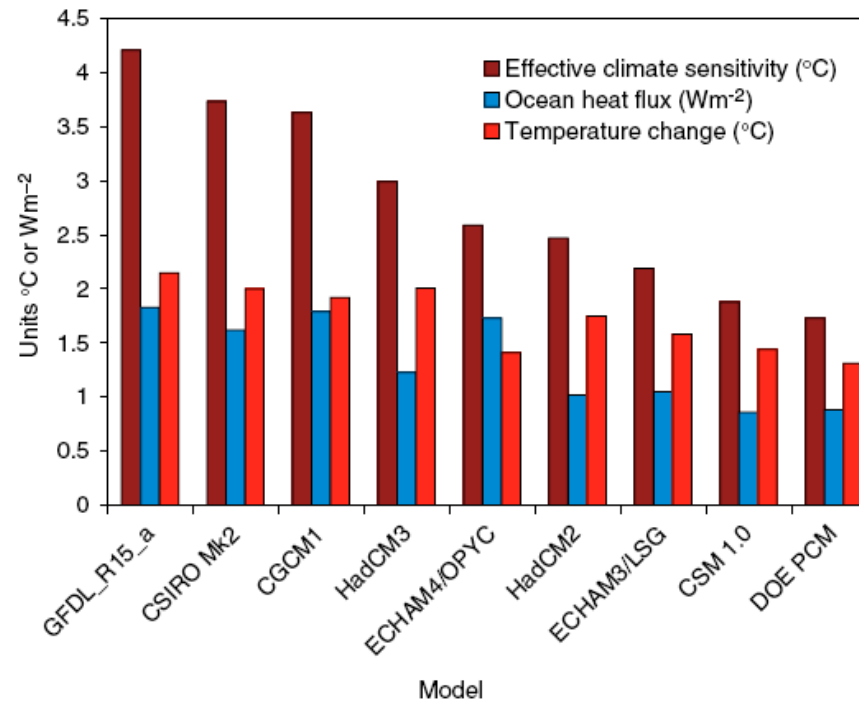
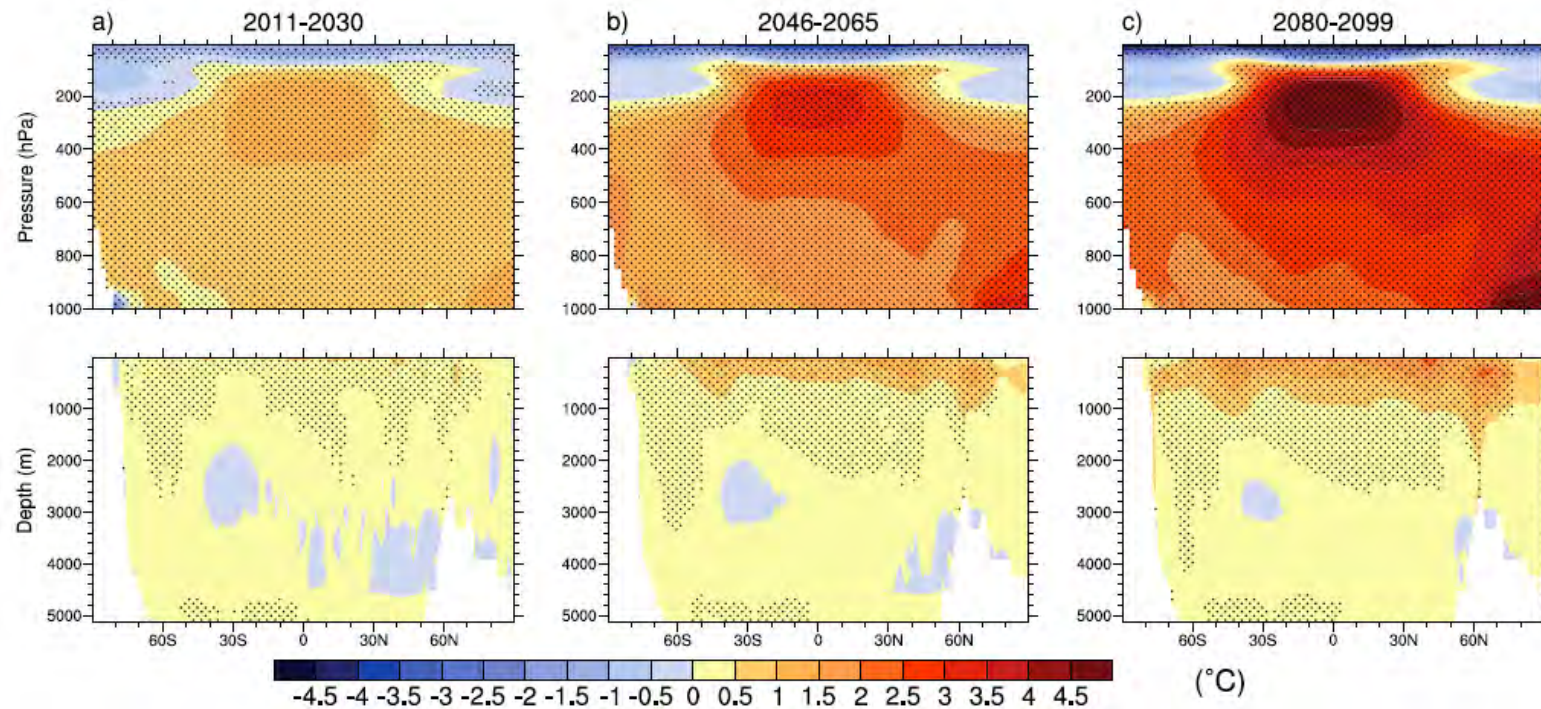


Figure 9.20: Comparison of CMIP2 model results for 20-year average values centred on year 70, the time of CO₂ doubling. Values are shown for the effective climate sensitivity, the net heat flux across the ocean surface multiplied by the ocean fraction and the global mean temperature change (TCR).

IPCC TAR, 2001

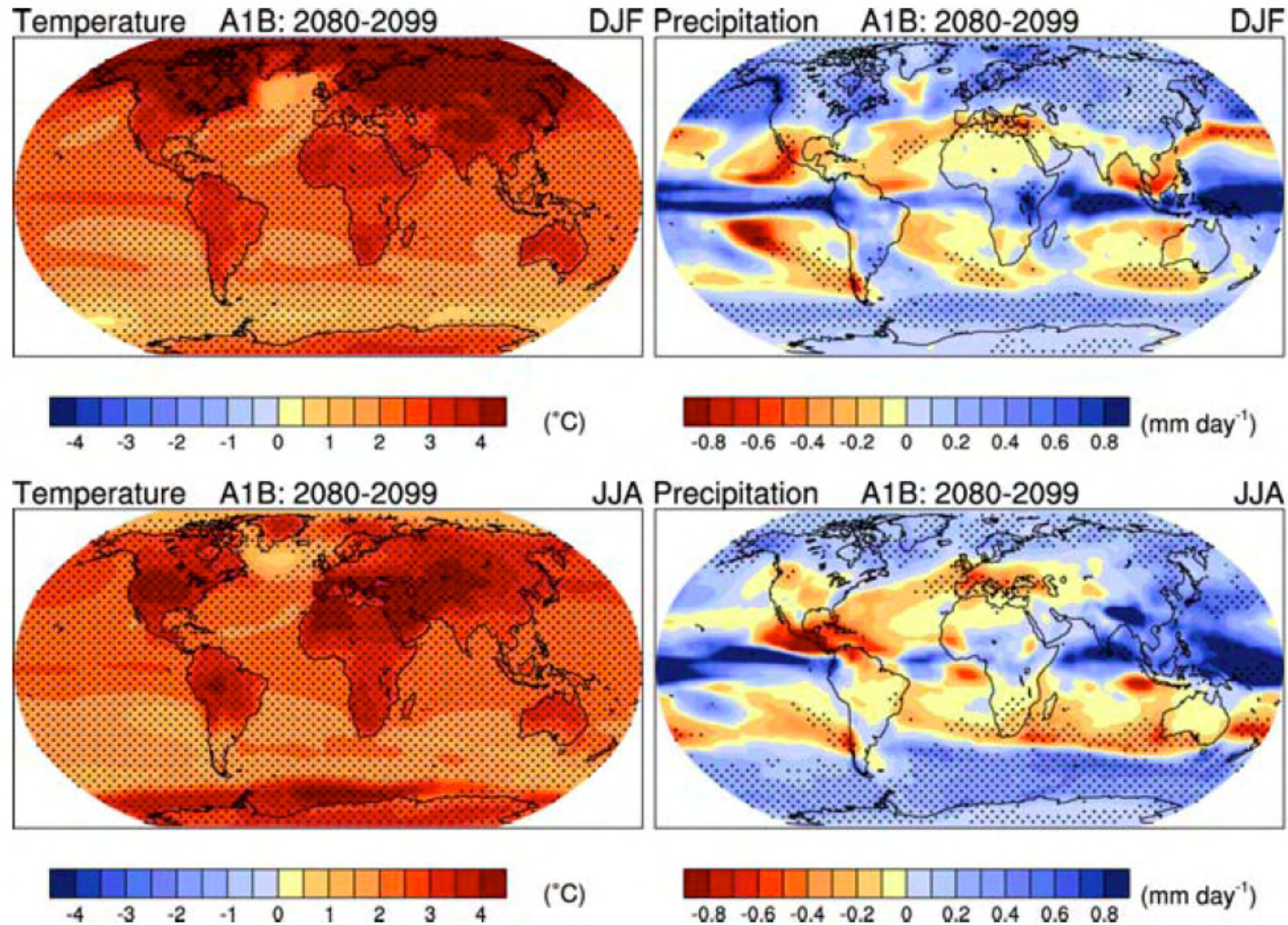
- The range of transient response is 3X smaller than the equilibrated sensitivity.
- Therefore the multi-model set of short-term predictions should be more consistent.

Atmospheric temperature changes



- Increases in tropospheric temperatures are manifest by 2030.
- Warming by 2030 exceeds multi-model variability by at least 1σ .

Low confidence in impact on rainfall

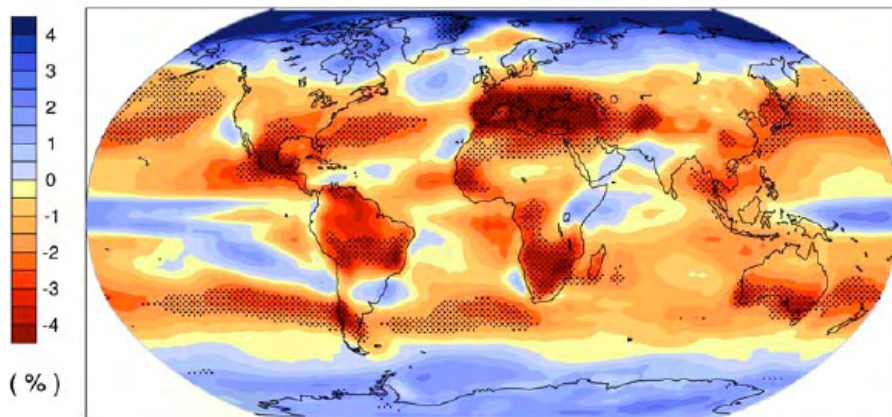


IPCC AR4, 2007

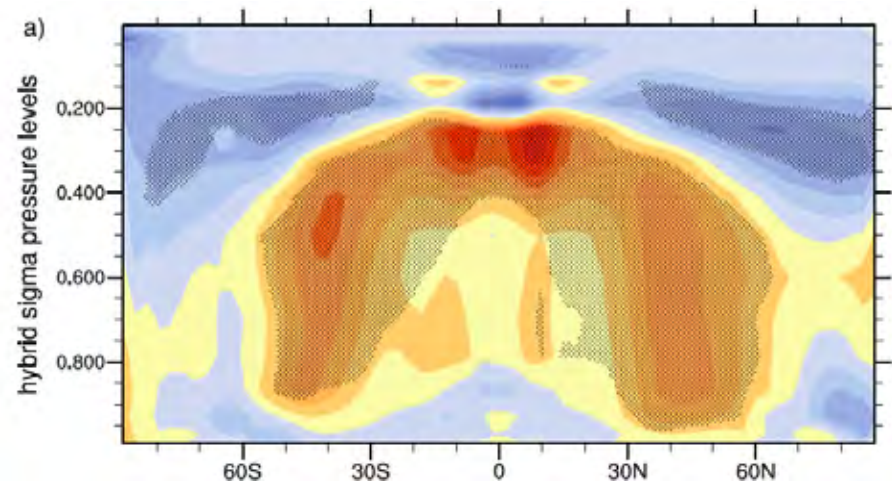
Low confidence in cloud evolution



Change in cloud amount in 21st century: A1B Scenario



IPCC AR4, 2007

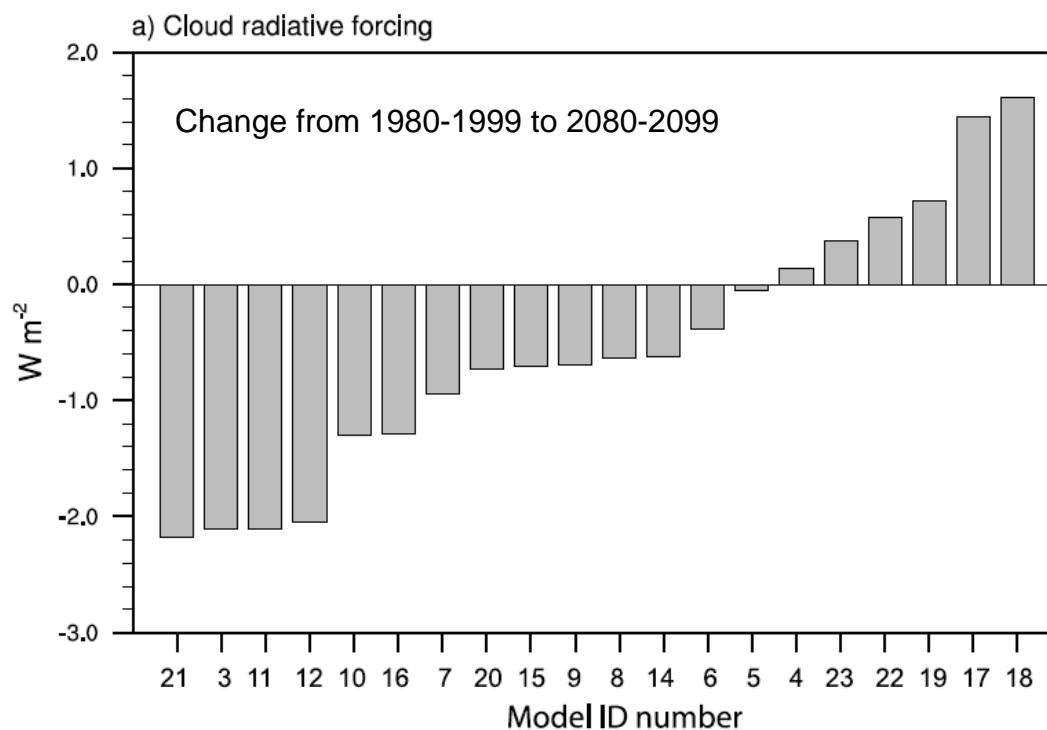


- Models do not agree on sign of cloud changes over much of globe.
- Models do agree on 3 to 4% decrease in upper tropospheric clouds.

Uncertain cloud radiative response



Change in cloud radiative effects in 21st century: A1B Scenario

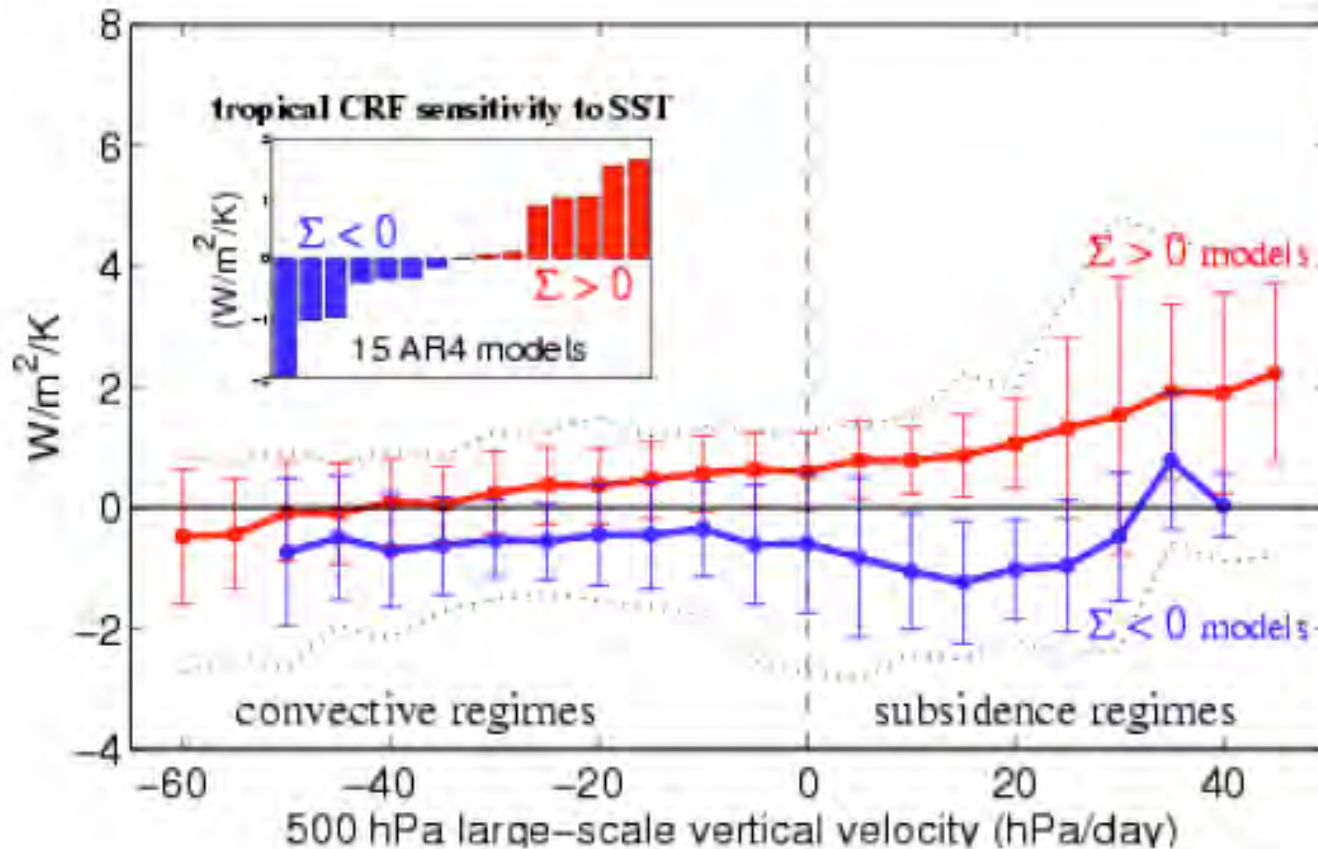


- Models do not converge on sign of change in cloud radiative effects.
- Trends in cloud radiative effects have magnitude $< 0.2 Wm^{-2} decade^{-1}$.

Low confidence in cloud feedbacks



Change in cloud radiative effects: 1% CO₂/year simulations



IPCC AR4, 2007

CLARREO and future climate change

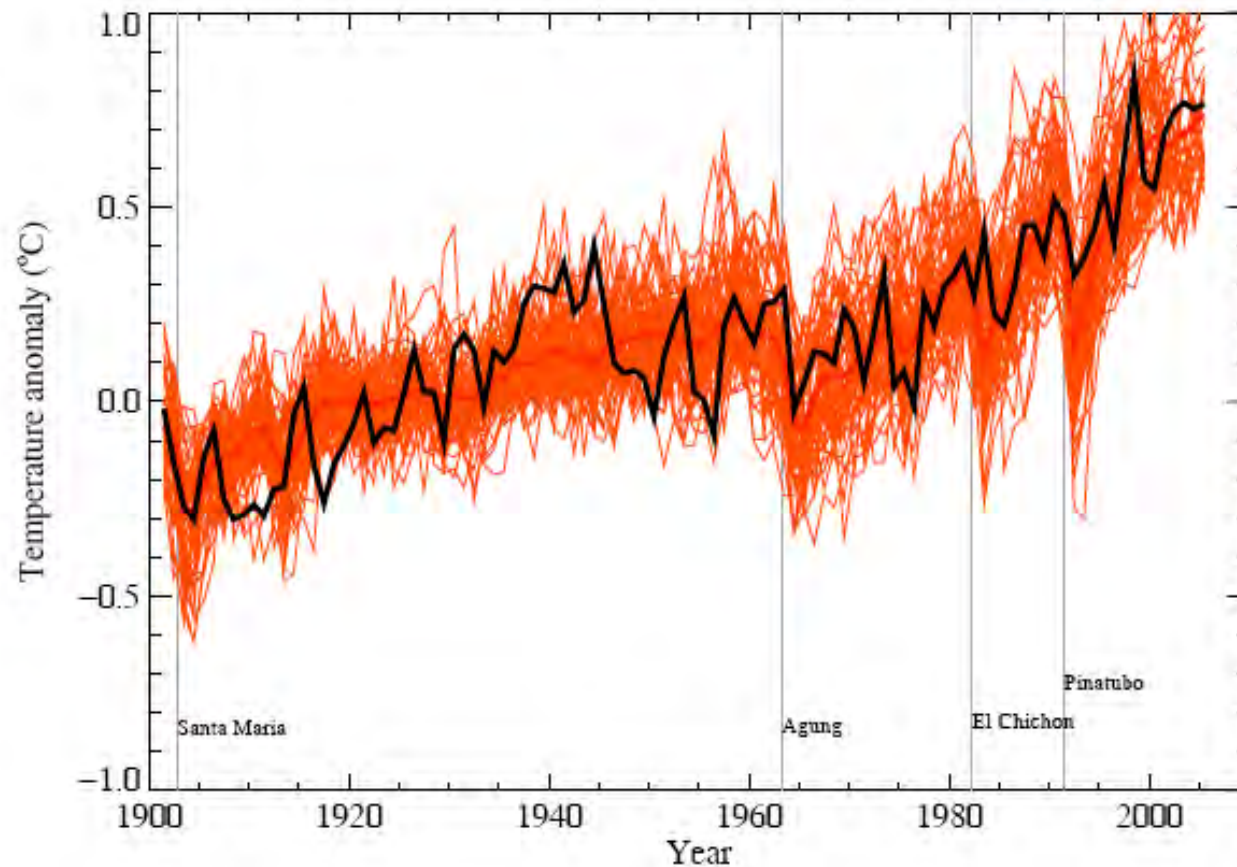


- Warming over next 30 years should be significant.
- Warming of upper atmosphere is a robust prediction.
- Warming over next 30 years may not help determine the most realistic models or emissions trajectories.
- However, information on sign of cloud feedbacks could discriminate O(50%) more realistic models.
- Will predicted trends in high clouds be validated?

Confrontation of models with data



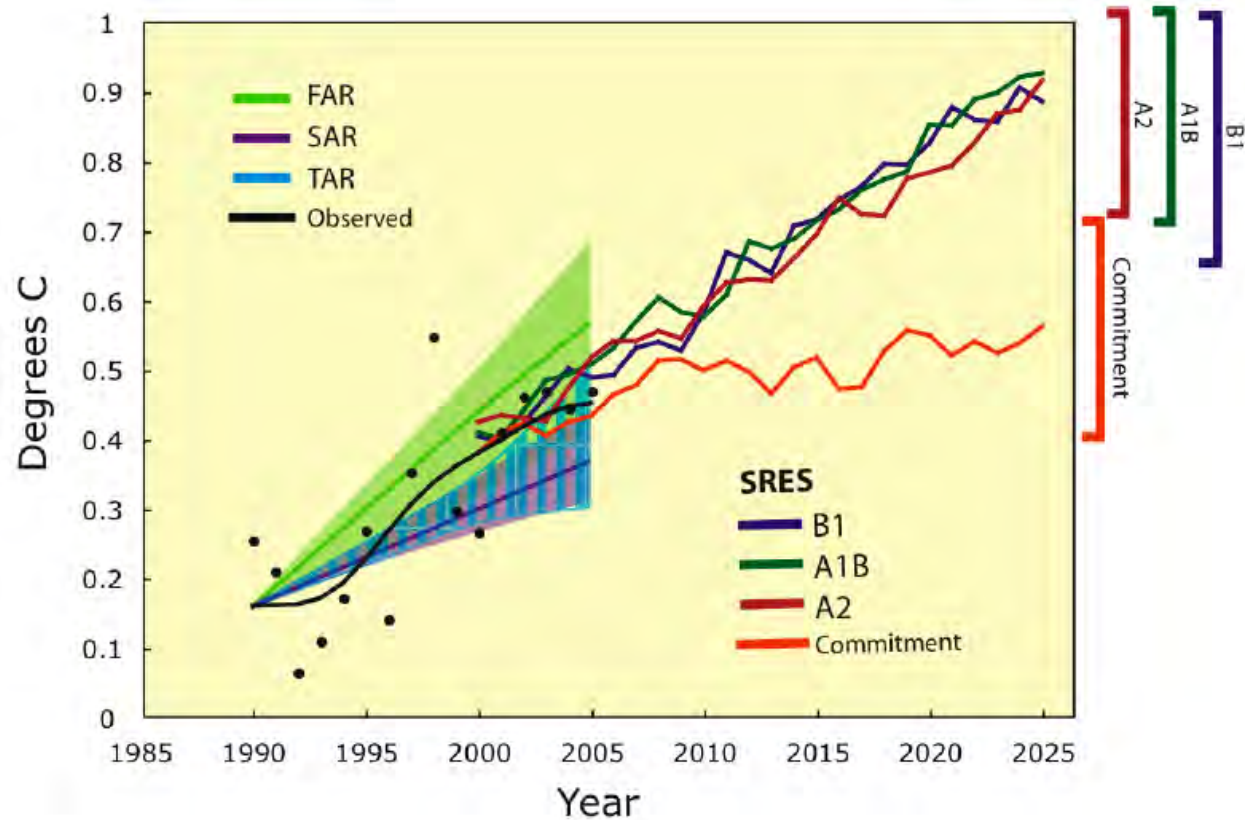
Global mean near-surface air temperature for the 20th C.



Veracity of near-term predictions



Modeled and predicted temperature anomalies from 1961-1990

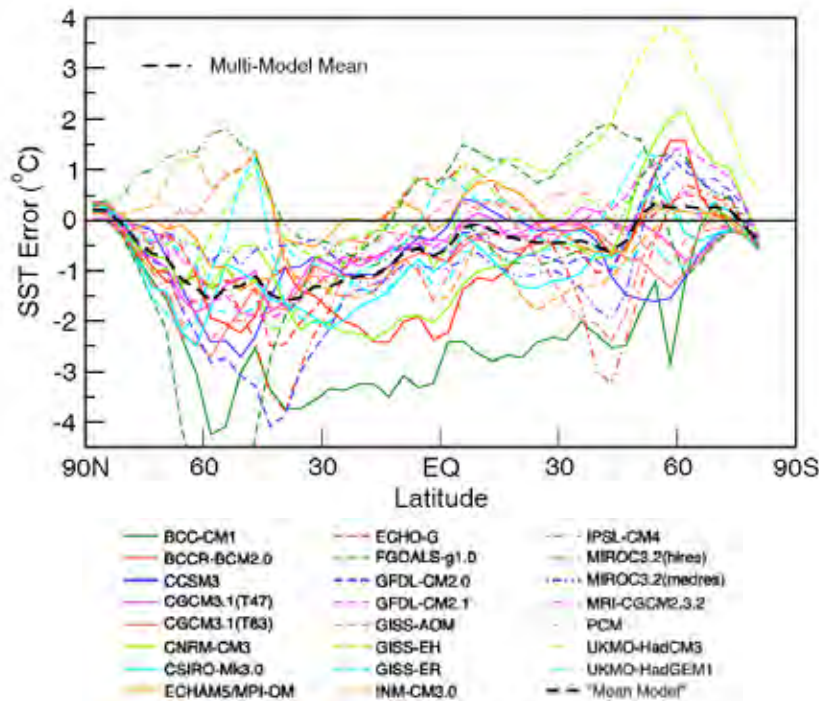


- Predicted rate since start of IPCC is 0.15 to 0.3 K decade⁻¹.
- Observed rate of increase is 0.2 K decade⁻¹.

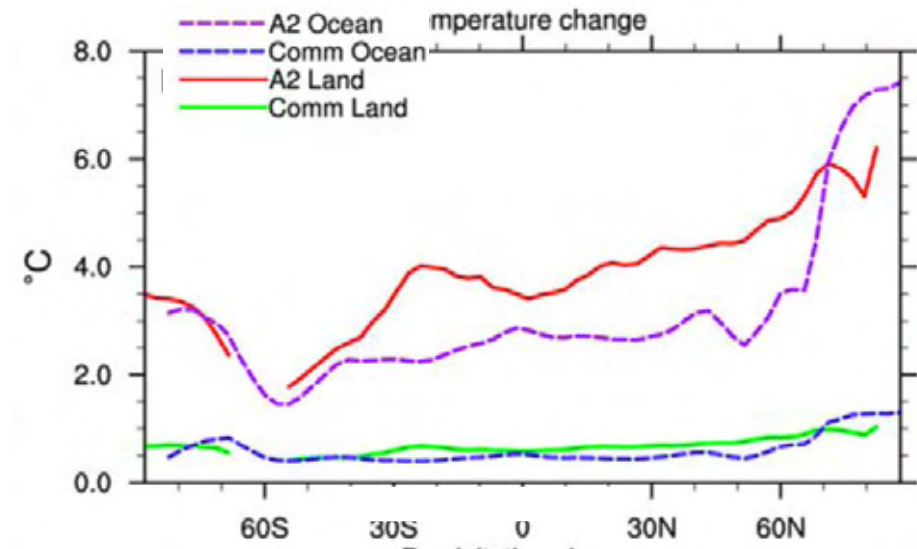
Evaluation of climate models



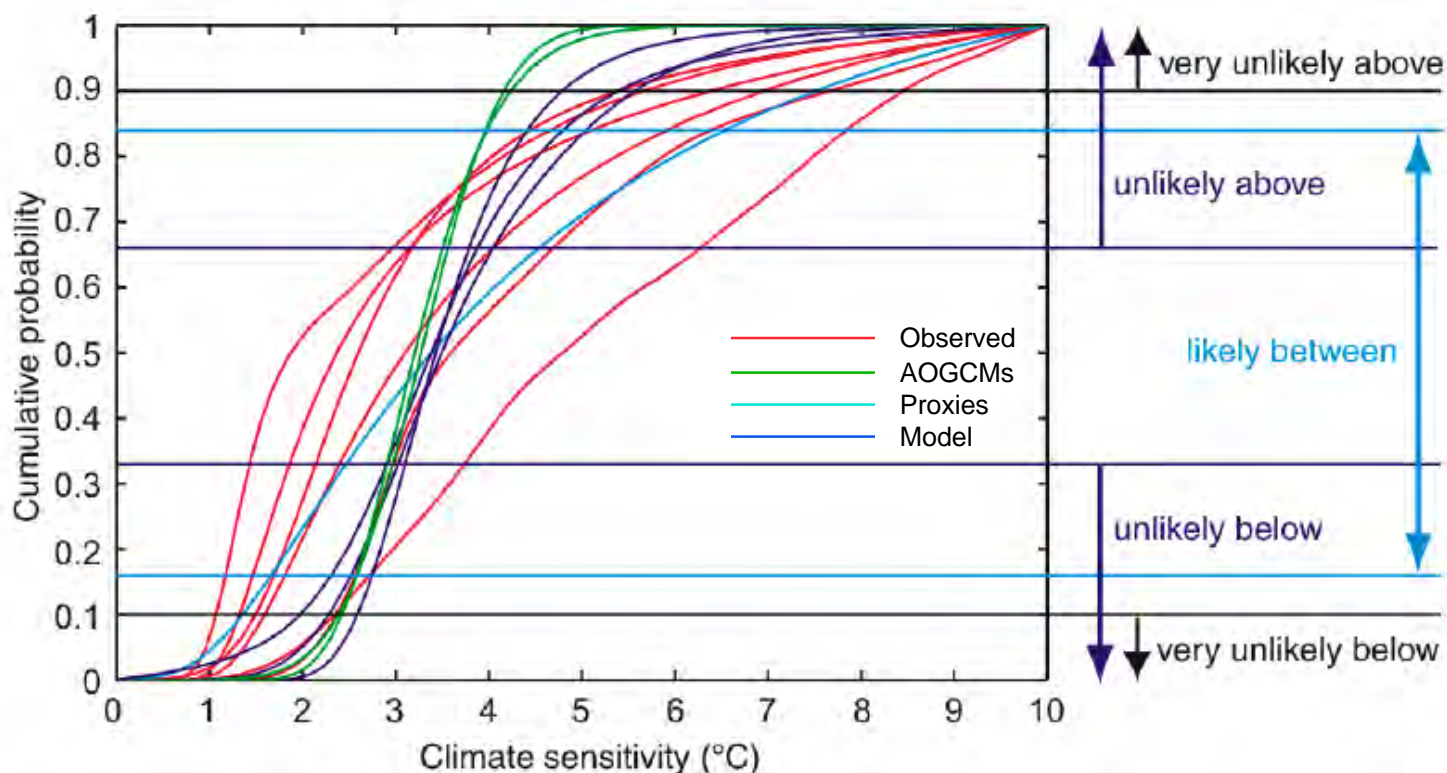
Modeled SST, 1980-1999



SST Change, 2080-2099



Distribution of climate sensitivity



- Equilibrium climate sensitivity is likely between 2 to 4.5K.
- Most likely value of equilibrium climate sensitivity is about 3K.
- Very high values (> 6K) cannot be excluded.

Issues for testing climate models



- **What tests are necessary and sufficient for accurate predictions?**
- **How are observables and sensitivity fundamentally related?**
- **We need empirical estimates of sensitivity that are robust to uncertainties in historical forcing.**
- **Fluctuation-dissipation theory links sensitivity to 2nd-order statistics (lagged correlations) of observables.**
- **This theory is not utilized in current assessments.**
- **Observational and model capabilities should be designed with tests of this theory as a top priority.**

Suggestions for near-term research



- **Perturbed physics ensembles are useful frameworks for linking observables and climate sensitivity.**
- **Existing ensembles provide traditional climate diagnostics.**
- **Range of sensitivity is weakly constrained using traditional climate diagnostics.**
- **It would be very useful to build a new ensemble designed for:**
 - **Emulation of CLARREO instrumentation**
 - **New diagnostics enabled by CLARREO instrumentation**
 - **Comprehensive tests of the connection between short-term correlations and climate sensitivity.**